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TECHNICAL REPORT

Computational tools for spacecraft electrostatic cleanliness and payload accomodation analysis - SPIS Science - Validation Test Plan (VTP)

Authors: V. GÉNOT (IRAP),
A. ERIKSSON (IRF),
C. CULLY (IRF), J.-CH. MATÉO-VÉLEZ,
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SPACE ENVIRONMENT DEPARTMENT

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Author abstract

This document describes the validation cases (VCs) to be simulated within "Computational tools for spacecraft electrostatic cleanliness and payload accommodation analysis", here called "SPIS-SCIENCE". SPIS-SCI aims at extending the capabilities of SPIS modeling framework for accurate evaluation of low-level surface electrostatic charging of science missions with low-energy plasma instruments.

Keywords

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Computational tools for spacecraft electrostatic cleanliness and payload accommodation analysis

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SPIS-SCIENCE

VALIDATION TEST PLAN (VTP)

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Validation Test Plan (VTP)

June 2011

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1. SUMMARY

1.1. Objectives

This document describes the validation cases (VCs) to be simulated within “Computational tools for spacecraft electrostatic cleanliness and payload accommodation analysis”, here called “SPIS-SCIENCE”. SPIS-SCI aims at extending the capabilities of SPIS modeling framework for accurate evaluation of low-level surface electrostatic charging of science missions with low-energy plasma instruments.

The user requirements are based on the inputs collected from the scientific community during the SPINE workshop organized by IRF at Uppsala, Sweden, January 17-19, 2011 [SPINE WS].

Section 2 presents the scope of the validation case studies.

Section 3 presents the proposed validation cases.

1.2. Acronyms

CAA	Cluster Active Archive (http://caa.estec.esa.int/)
CHAMP	CHAllenging Mini-satellite Payload
CME	Coronal Mass Ejection
EAS	Electron Analyzer Sensor
EFW	Cluster Electric Fields and Waves instrument
GUI	Graphical User Interface
INMS	Cassini Ion and Neutral Mass Spectrometer
IRAP	Institut de Recherche en Astrophysique et Planétologie
IRF	Swedish Institute of Space Physics
JGO	Jupiter Ganymede Orbiter (ESA)
MMO	BepiColombo Mercury Magnetospheric Orbiter (JAXA)
MMS	Magnetospheric MultiScale mission (NASA)
MPO	BepiColombo Mercury Planetary Orbiter (ESA)
MSSL	Mullard Space Science Laboratory (UK)
ONERA	Office National d'Etudes et de Recherches Aérospatiales
PDS	Planetary Data System (http://pds.nasa.gov/)
PEACE	Cluster Plasma Electron And Current Experiment on Cluster
RPC	Rosetta Plasma Consortium
RPC-LAP	RPC Langmuir probe instrument
RPWS	Cassini Radio and Plasma Wave Science instrument suite
RPWS-LP	RPWS Langmuir probe instrument
SEP	Solar Energetic Particle
S/C	Spacecraft
SEEE	Secondary Electron Emission from Electron impact
SolO	Solar Orbiter (ESA)
SOW	Statement Of Work
SP+	Solar Probe plus (NASA)
SPIS	Spacecraft Plasma Interaction Software

SPIS-CORE website	Current SPIS development branch available on spis.org
SPIS-SCI	Computational tools for spacecraft electrostatic cleanliness and payload accomodation analysis
SR	Software Requirement for SPIS-SCI
SWA	Solar Wind Analyzer
TBD	To be defined
UR	User Requirement for SPIS-SCI
VC	Validation Case
wrt	with respect to

1.3. Reference Documents

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2. SCOPE OF THE VALIDATION CASES

The validation cases are outlined in the [SoW, p. 10]:

"A set of at least five validation test cases representative of the effects discussed in Task 1 shall be identified and be preferably relevant to the plasma interaction effects expected on Cross-scale, Solar orbiter, or EJSM/Laplace and submitted to ESA for approval. Use of published data, e.g., on Cluster, NASA Galileo or Cassini shall be considered."

The validation cases we propose are intended to validate the code in two respects:

1. Show that simulation cases considered of high interest by the scientific community can be meaningfully addressed by the upgraded SPIS code.
2. Compare the SPIS simulation output to existing data and/or independent simulations, to verify the operational capacity of SPIS in realistic simulations.

Note that the verification of each upgraded algorithm or feature is performed as a part of WP400 by ONERA/ARTENUM during the development, and is not intended for the validation cases (WP500).

To provide validation as defined above, the selected validation cases should ideally:

- Use key features of the upgraded SPIS code
- Span a large range of plasma parameters
- Represent several types of spacecraft and of instrument locations (spinners/3-axis stabilized, wire booms/solid booms/sc mounted)
- Be relevant to future missions
- Be comparable to existing data, other studies, and/or simulations with other codes

Each validation case does not necessarily have to span all these, but the total must be balanced in these respects.

3. VALIDATION CASES

This section presents all considered validation cases. Section 3.1 is a list of all cases suggested based on the discussions with the science community during [SPINE WS]. These cases have a lot of overlap in terms of the SPIS features they use, the environmental conditions they apply to, and their spacecraft geometries. We assign each a priority and discuss briefly the reasons for this priority. In Section 3.2 we suggest a subset of five cases that span the range of these variables and demonstrate the use of the main features of the SPIS development within SPIS-SCI.

3.1. All proposed validation cases

3.1.1. VC-1: Cluster E-field measurements

Number	VC-1
Title	Cluster E-field measurements
Priority	High (1) (community demand) Very suitable as a test case (Section 3.2.1): • Requires thin wire booms, test particle tracking to establish probe current, multiple photoelectron populations • Well defined comparison (boom shortening effect), possible to quantitatively compare to independent simulations and in-orbit data • High scientific interest for Cluster, MMS, and BepiColombo MMO
Origin	SPINE workshop
Scientific case	• Model effective antenna length (boom shortening effect) in various plasma environments with different Debye lengths
Validation criteria	• Comparison with other code: Compare the effective antenna length in the long Debye-length regime with published results from C. Cully's code [Cully2007] • Comparison with data: Extend the boom-shortening results to the finite Debye-length regime and compare with published in-orbit result [Mihaljcic2010]
Comments	
List of relevant UR	PPD-004, PPD-005, PPD-006, FGS-001, FGS-002, FGS-003, FGS-004, FGS-005, FGS-006, FGS-007, PE-001
List of relevant SR	TBD
Timeline	
Support data and related database access	Cluster PEACE, EFW (CAA)
Linked to future mission(s)	MMS, BepiColombo MMO

3.1.2. VC-2: Cluster electron measurements

Number	VC-2
Title	Cluster electron measurements
Priority	High (1) (community demand) Very suitable as a validation case with high interest in the science community, excellent and easily available (CAA) data to compare to, several published studies, and good bearing on future projects.
Origin	SPINE workshop
Scientific case	• Understand spacecraft photoelectron impact on electron instrument and Langmuir probes. Compute predicted electron distribution functions and compare to observations.
Validation criteria	• Comparison to data: [Szita2001]. • Comparison to data: [Pedersen2008] • Comparison to model: [Thiébault2004] • See presentations and SPIS study proposals by A. Fazakerley at SPINE workshops (16th and 17th)
Comments	• Existing SPIS model ? • Tracking photoelectrons to an electron detector on the spacecraft from various spacecraft parts, including biased elements far out on wire, is a demanding test case for an upgraded code • Comparison to bias sweeps from the EFW instrument in Langmuir probe mode • Contact person : A. Fazakerley (MSSL)
List of relevant UR	PS-001, PS-002, PS-003, PS-004, PS-005, PS-006, FGS-001, PE-002, PPD-001, PPD-002, PPD-003
List of relevant SR	TBD
Timeline	
Support data and related database access	Cluster EFW, Cluster PEACE (CAA)
Linked to future mission(s)	MMS, Bepi-Colombo

3.1.3. *VC-3: Rosetta*

Number	VC-3
Title	Rosetta
Priority	High (2) Relevant validation case of clear scientific interest with previous simulations, an existing SPIS model, and a useful database. However, the wake and photoelectron issues are similar to Solar Orbiter (VC-4, VC-5), which is presently in higher demand with the scientific community, and Cassini (VC-12), which has a much bigger and better analyzed dataset spanning a larger variety of plasma conditions. On balance, SolO and Cassini together may outweigh Rosetta.
Origin	
Scientific case	• Reproduce/confirm simulated wake/photo-cloud potentials • Compare to observed potentials on Langmuir probe in E-field mode • Simulate Langmuir probe bias sweeps (once back tracking functionality is implemented)
Validation criteria	• Comparison with first earlier SPIS study: assess differences when UR are implemented • Compare to observed Langmuir sweeps
Comments	• Existing SPIS models [Sjögren2009] • Reinvestigation of previous SPIS simulations: [Sjögren2009] • Comparison with previous study: [Roussell2004] • Probe bias sweeps can also be compared to Cassini RPWI-LP data
List of relevant UR	PPD-004, PPD-005, PPD-006, FGS-001, FGS-002, FGS-003, FGS-004, FGS-005, FGS-006, FGS-007, PE-001
List of relevant SR	TBD
Time line	
Support data and related database access	Rosetta RPC data
Linked to future mission(s)	SolO, SP+, JGO

3.1.4. *VC-4: Solar Orbiter E-field measurements and wake*

Number	VC-4
Title	Solar Orbiter E-field measurements and wake
Priority	High (1) (community demand)
Origin	SPINE workshop
Scientific case	• Investigation of the wake effect on the electron instrument (located at the end of a boom in the wake) • Model of spacecraft potential: emphasis on the potential pattern near the antennas and the influence on the electric field measurement • Dependence on environmental parameters • Investigation of the effects of the non-conducting solar panels Test case • Simple model with current version of SPIS and then comparison with new developments • For different solar panel positions (facing or 35°), and heliocentric positions 10R_S, 0.15, 0.3, 0.6, 1 AU • Average and extreme solar wind conditions (regular slow and fast winds, plus typical CME and SEP cases) • Compute wake structure and potential at antennas
Validation criteria	• Comparison with model in the Solar Probe Plus context: [Ergun2010] • Comparison with wake simulations for Rosetta: [Sjögren2009] • Comparison with Helios data at 0.3 AU: [Isensee1981]
Comments	• Spacecraft model to be provided by ESA • Contact persons : M. Maksimovic (LESIA), V. Krasnoselskikh (LPC2E)
List of relevant UR	ESC-001, ESC-003, PS-008, FGS-004, SP-004
List of relevant SR	TBD
Time line	PDR in November 2011 (early results could be presented)
Support data and related database access	STEREO SWEA (SSC, CDPP), Ulysses SWOOPS, Helios, Wind 3DP (CDAWeb)
Linked to future mission(s)	Solar Probe Plus, Bepi-Colombo

3.1.5. VC-5: Solar Orbiter electron measurements

Number	VC-5
Title	Solar Orbiter electron measurements
Priority	High (1) (community demand)
Origin	SPINE workshop
Scientific case	• Investigation on the photoelectron role in electron instruments and the possible development of a potential barrier around the spacecraft. Compute predicted electron distribution functions and compare to observations. Test case • Simple model with current version of SPIS and then comparison with new developments • For different solar panel positions (facing or 35°), and heliocentric positions 10R_S, 0.15, 0.3, 0.6, 1 AU • Average and extreme solar wind conditions (regular slow and fast winds, plus typical CME and SEP cases)
Validation criteria	• Comparison with model in the Solar Probe Plus context: [Ergun2010] • Comparison with Helios data at 0.3 AU: [Isensee1981]
Comments	• Spacecraft model to be provided by ESA • Comparison to model: [Thiébault2004] • Contact persons : M. Maksimovic (LESIA), V. Krasnoselskikh (LPC2E)
List of relevant UR	PS-001, PS-002, PS-003, PS-004, PS-005, PS-006, PS-008, FGS-001, PE-002, ESC-001, PPD-001, PPD-002, PPD-003
List of relevant SR	TBD
Time line	PDR in November 2011 (first results could be presented)
Support data and related database access	STEREO SWEA (SSC, CDPP), Ulysses SWOOPS, Helios, Wind 3DP (CDAWeb)
Linked to future mission(s)	Solar Probe Plus, Bepi-Colombo

3.1.6. VC-6: EJSM/JGO

Number	VC-6
Title	EJSM/JGO
Priority	Medium Of clear scientific interest, but limited availability of comparison data. The relevant environments and spacecraft geometries are covered by other test cases: Rosetta and Solar Orbiter (VC-4, VC-5) are good analogies for the spacecraft, and Cassini (VC-12) for the environment.
Origin	
Scientific case	• Detailed characterization of the electrostatic environment around plasma instruments (including Langmuir probes) onboard EJSM/JGO as it will cruise in very varied medium (from Solar Wind to inner jovian magnetosphere and Ganymede environments) • Effect on very low energy ion (below 1eV) measurements • Wake effect investigation • Model of spacecraft potential
Validation criteria	• For not too dense plasma : validation with C. Cully's code • For solar wind conditions: comparison to Rosetta LAP data
Comments	• Spacecraft model to be provided by ESA but still 2/3 design in competition to be decided probably late in the project (date TBD) hence the lower priority • Contact persons: A. Wielders (ESA)
List of relevant UR	ESC-001, ESC-003, PS-019, FGS-004, FGS-005, FGS-008
List of relevant SR	TBD
Timeline	
Support data and related database access	Cassini CAPS and RPWS-LP, Galileo (PDS)
Linked to future mission(s)	Juno

3.1.7. VC-7: Bepi-colombo/MMO

Number	VC-7
Title	Bepi-colombo/MMO
Priority	Medium Clear scientific interest, but conceptual issues covered by other cases: Cluster for the wire booms (VC-1) and electron trajectories (VC-2), Solar Orbiter for the solar panel interconnects (VC-4, VC5)
Origin	SPINE workshop
Scientific case	• Assess spacecraft potential differential effects on electron trajectory/energy at both electron instruments (MEA) mounted at 90° on spinning platform • Comparing boom shortening effect with C. Cully's code • Large potential difference at solar panel interconnects (~200V)
Validation criteria	• Comparison with particle trajectories computed from simulations with the TRACE code (A. Fedorov, IRAP) for the interconnect issue (possibility to include the magnetic field)
Comments	Spacecraft model may be hard to be obtain (Japan-led) hence the lower priority
List of relevant UR	FGS-001, FGS-002, FGS-003, SP-007, PPD-001, PPD-002, PPD-003
List of relevant SR	TBD
Time line	
Support data and related database access	Messenger (PDS) Cluster
Linked to future mission(s)	Solar Orbiter

3.1.8. VC-8: Bepi-Colombo/MPO

Number	VC-8
Title	Bepi-Colombo/MPO
Priority	Low Issues covered by Solar Orbiter cases (VC-4, VC-5).
Origin	
Scientific case	• Wake effect due to solar panels • Low energy ion measurements
Validation criteria	
Comments	• No discussion on this spacecraft during the SPINE workshop (hence the low priority) • Spacecraft model could be obtained from ESA • Contact person: H. Laakso (ESA, deputy project-scientist)
List of relevant UR	FGS-001, ESC-003
List of relevant SR	TBD
Time line	
Support data and related database access	Messenger (PDS)
Linked to future mission(s)	Solar Orbiter

3.1.9. VC-9: Magnetic/electric perturbations on CHAMP/Swarm

Number	VC-9
Title	Magnetic/electric perturbations on CHAMP/Swarm
Priority	High (2) Clear scientific interest. Shorter Debye length and gyroradius than in any other suggested validation case. However, Cassini (VC-12) shares the main features (small probes on big s/c, cold and dense environment), and has a huge database to compare to.
Origin	ESA demand, see D. Rodgers presentation [SPINE
Scientific case	• simulate the behaviour of the Langmuir probe and in particular the geometrical blocking due to nearby spacecraft • improve the interconnect approximation (i.e. combining small interconnects into larger surfaces) • test the inclusion of I-V curves of solar arrays
Validation criteria	• Comparison with ESA previous study • Comparison with results from alternative code PTetra: [Marchand2010]
Comments	• CHAMP and Swarm models exist at ESA • See also http://space-env.esa.int/index.php/ESA-ESTEC-Space-Environment-TEC-EES/articles/champ-swarm-spis.html
List of relevant UR	ESC-002, PPD-004, PPD-005, PPD-006, PS-007, FGS-004
List of relevant SR	TBD
Time line	
Support data and related database access	Champ (http://op.gfz-potsdam.de/champ/orbit/index_PRD.html ?)
Linked to future mission(s)	Swarm

3.1.10. VC-10: Demeter

Number	VC-10
Title	Demeter
Priority	Medium A well studied mission with a good dataset and previous studies to compare to. Environment and issues similar to Swarm (VC-9) and Cassini (VC-12). Less relevance for upcoming missions than most other validation cases suggested. The far wake study can likely not be accommodated in a study with SPIS with hardware resources currently available.
Origin	SPINE workshop
Scientific case	• Far wake study • Wake anisotropy wrt to magnetic field (1 eV proton at 710 km has R_L=3-6 m in dipolar field)
Validation criteria	• Comparison with SPIS simulation (see [Artenum2010a, Artenum2010b]) • Comparison with [Marchand2010] • Comparison with [Ivchenko2001] (in-orbit study of anisotropic wake in the ionosphere at 1000 km from the Astrid-2 satellite)
Comments	• Existing SPIS model • Contact person : J.J. Berthelier (LATMOS)
List of relevant UR	ESC-002, ESC-003, FGS-004
List of relevant SR	TBD
Time line	TBD
Support data and related database access	Demeter (LPC2E)
Linked to future mission(s)	

3.1.11. VC-11: STEREO

Number	VC-11
Title	STEREO
Priority	Medium Does not add much outside the Solar Orbiter simulations, for which the community demands are high.
Origin	SPINE workshop
Scientific case	• Investigation of the wake effects on the electron measurements (located at the end of a boom in both the shadow and wake) • Model the shape of the potential and how asymmetries are important for electron instruments. Test case • Do this for both average and extreme solar wind conditions (regular slow and fast wind, plus typical CME and SEP cases; e.g., 4 cases)
Validation criteria	• Berkeley (surely) has simulations already, but can they share?
Comments	• Not sure how to obtain spacecraft design. (hence the lower priority) • No discussion on this spacecraft during the SPINE workshop • May be redundant with Solar Orbiter cases • Contact: J.A. Sauvaud (IRAP)
List of relevant UR	ESC-003, FGS-001, PPD-001, PPD-002, PPD-003
List of relevant SR	TBD
Time line	TBD
Support data and related database access	STEREO SWA (IRAP, STEREO Science Center, CDAWeb)
Linked to future mission(s)	Solar Orbiter

3.1.12. VC-12: Cassini electron measurements

Number	VC-12
Title	Cassini electron measurements
Priority	High (1) (community demand)
Origin	SPINE workshop
Scientific case	• Understand spacecraft photoelectron impact on CAPS electron instrument and RPWS Langmuir probe in various regions of Saturn's magnetosphere, in particular in the inner magnetosphere where the neutral torus orbits • Understand effect of barrier formation on attractive Langmuir probe on a repelling spacecraft • Understand secondary emission effect on the Langmuir probes in the hot plasma disk [Garnier2011]
Validation criteria	Comparison to data: • [Lewis2010] • RPWS-LP probe bias sweeps (available at IRF) Comparison to models for Langmuir probe current: • [Jacobsen2009] (photoelectrons) • [Laframboise1974] and [Olsen2010] (barrier effect on repelling s/c)
Comments	• Spacecraft model (Cassini paper model available at http://saturn.jpl.nasa.gov/education/buildapapermodel/, or directly from JPL) • Existing SPIS model (at IRF and MSSL) • Previous SPIS simulations [Nilsson2009] • Approximate expressions for probe current decrease due to barrier effect by [Laframboise1974] and [Olson2010]
List of relevant UR	FGS-001, PPD-001, PPD-002, PPD-003, PPD-004, PS-001, PS-002, PS-003, PS-004, PS-005, PS-006, PE-002
List of relevant SR	TBD
Time line	TBD
Support data and related database access	Cassini CAPS ELS and IMS data (PDS, MSSL, GSFC, SwRI), Langmuir Probe data (IRF, Uppsala)
Linked to future mission(s)	EJSM (JEO)

3.1.13. VC-13: Cassini: Titan flybys

Number	VC-13
Title	Cassini: Titan flybys
Priority	Low Of scientific interest, but quite outside the scope of SPIS-SCI, as modelling the Cassini charging in this environment does not depend on the new development in this project. Such modelling is partly integrated in VC-12, as the s/c potential must be determined also there.
Origin	SPINE workshop
Scientific case	• Modelling of spacecraft charging during Titan flybys, under a variety of Local Time and solar illumination conditions
Validation criteria	Comparison to data: • [Sittler2006], [Sittler2010]
Comments	• Spacecraft model (Cassini paper model available at http://saturn.jpl.nasa.gov/education/buildapapermodel/, or directly from JPL) • Existing SPIS model (at MSSL)
List of relevant UR	ESC-001, PE-001, SP-002
List of relevant SR	TBD
Time line	TBD
Support data and related database access	Cassini CAPS ELS and IMS data (PDS, MSSL), Langmuir Probe data (IRF, Uppsala)
Linked to future mission(s)	EJSM (JEO)

3.1.14. VC-14: Cassini-Huygens modelling

Number	VC-14
Title	Cassini-Huygens modelling
Priority	Middle While of clear scientific interest, this has little to do with the improvements to SPIS in SPIS-SCI and is therefore considered less useful as a validation case.
Origin	SPINE workshop
Scientific case	• Modelling of Cassini-Huygens spacecraft charging before and after the release of the Huygens probe to identify any possible influences
Validation criteria	Comparison to data: • Sittler [Sittler2006], [Sittler2010] • RPWS-LP data (available at IRF)
Comments	• Spacecraft model (Cassini paper model available at http://saturn.jpl.nasa.gov/education/buildapapermodel/, or directly from JPL) • Probe model of Huygens attached to Cassini to begiven by ESA or JPL • Existing SPIS models (at IRF and MSSL)
List of relevant UR	SP-002, SP-007
List of relevant SR	TBD
Time line	TBD
Support data and related database access	Cassini CAPS ELS and IMS data (PDS, MSSL, GSFC, SwRI), Langmuir Probe data (IRF, Uppsala)
Linked to future mission(s)	EJSM (JEO)

3.2. Discussion of highest priority cases

We here propose a subset of the cases listed in Section 3.1, for each case detailing the possible simulations and discussing why this should be a particularly relevant case. An overview of how these cases relate to the existing and upcoming missions which are the driver behind SPIS-SCI is presented in Table 1

Table 1 - Relevance of the proposed validation cases and relations to available datasets and studies

Case	VC-1	VC-2	VC-4	VC-5	VC-12
Scope	Cluster E-field measurements	Cluster electron measurements	Solar Orbiter E-field measurements and wake	Solar Orbiter electron measurements	Cassini electron measurements
S/c relevance	Bepi MMO MMS	Bepi MMO MMS	Rosetta JGO SP+ Demeter	SolO Bepi MPO Rosetta SP+	JGO Rosetta
Plasma conditions relevance	Bepi MMO MMS	Bepi MMO MMS	Bepi MMO Bepi MPO SP+	Bepi MMO Bepi MPO SP+	JGO Rosetta Demeter
Relevant existing databases	Cluster	Cluster	Rosetta	Rosetta Helios Stereo	Cassini
Relevant previous studies	[Cully2007] [Mihljcic2010] [Miyake2011] [Thiébault2003] [Thiébault2004]	[Mihaljcic2010] [Pedersen2008] [Szita2001] [Thiébault2003] [Thiébault2004]	[Engwall2006]	[Ergun2010] [Isensee1981] [Katz2001] [Sjögren2009]	[Jacobsen2009] [Laframboise1974] [Lewis2010] [Nilsson2009] [Olson2010]

3.2.1. VC-1 Cluster E-field

Cluster shows several attractive features for a SPIS-SCI validation case:

- Complete set of high-sensitivity plasma instruments onboard, allowing good characterization of the environment and good comparison to simulation results
- Large and accessible database (CAA and local access at IRF and IRAP)
- Several studies on s/c-plasma interaction issues previously published
- High interest from the scientific community
- Relevance for Bepi-Colombo MMO, MMS, Themis, and other upcoming and previously flying spinners with double-probe instruments

For this validation case, we will model the spacecraft, wire booms, spherical probes and adjacent electrical elements as similarly to the previous investigation by [Cully2007] as possible (Figure 1). The [Cully2007] results apply to a long Debye length situation, while the SPIS simulations will allow us to study also denser plasma situations. Comparison data for varying Debye lengths are available in the in-orbit study by [Mihaljcic2010] (Figure 2). The main test criterion is very well defined: to find the effective antenna length, which is directly comparable to the quantitative results in [Cully2007] and [Mihaljcic2010]. It is also possible to compare at least qualitatively to an independent PIC simulation study for varying Debye lengths by [Miyake2011].

VC-1 is a demanding test case, as it includes the modeling of a system of widely varying dimensions, from the 0.3 mm thickness of the outermost thin wire to the 88 m probe-to-probe distance, and the currents to small bodies. It crucially depends on the implementation of the test particle tracking to get sufficient currents for establishing probe current-voltage characteristics.

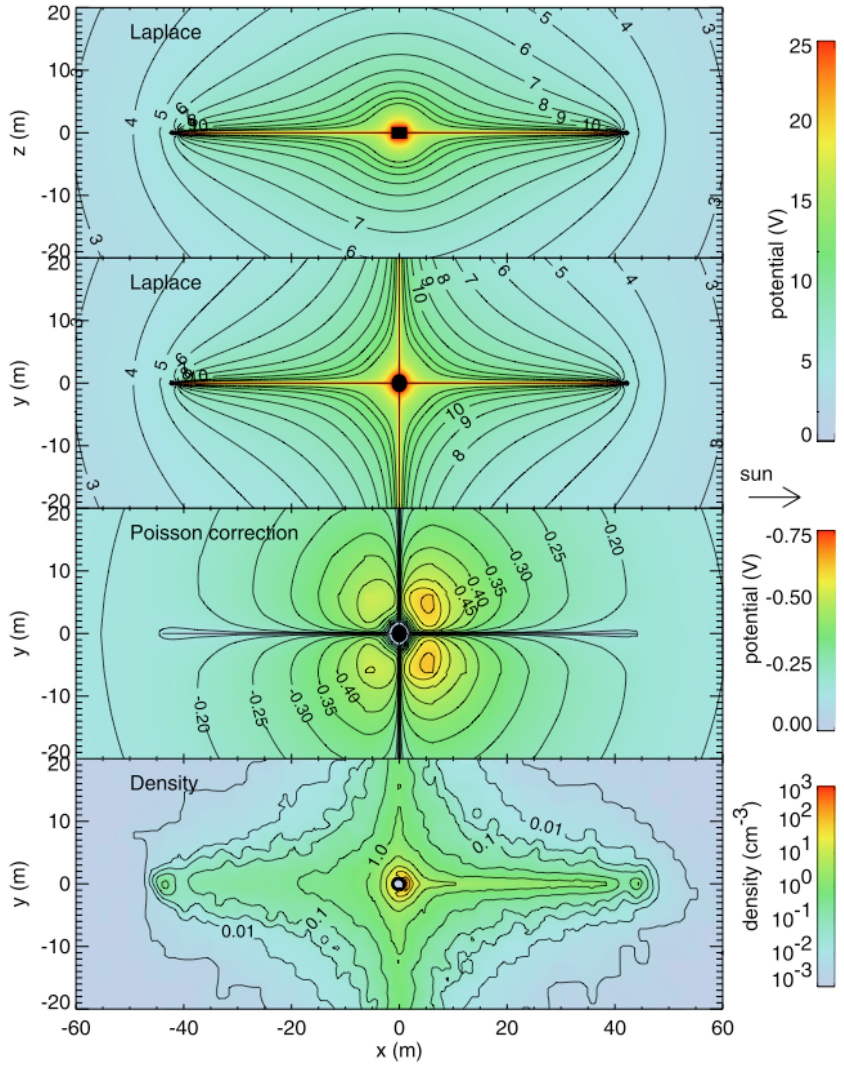

Figure 1 - Simulations of potential and photoelectron density around a Cluster satellite, including fully resolved wire booms. [Cully2007]

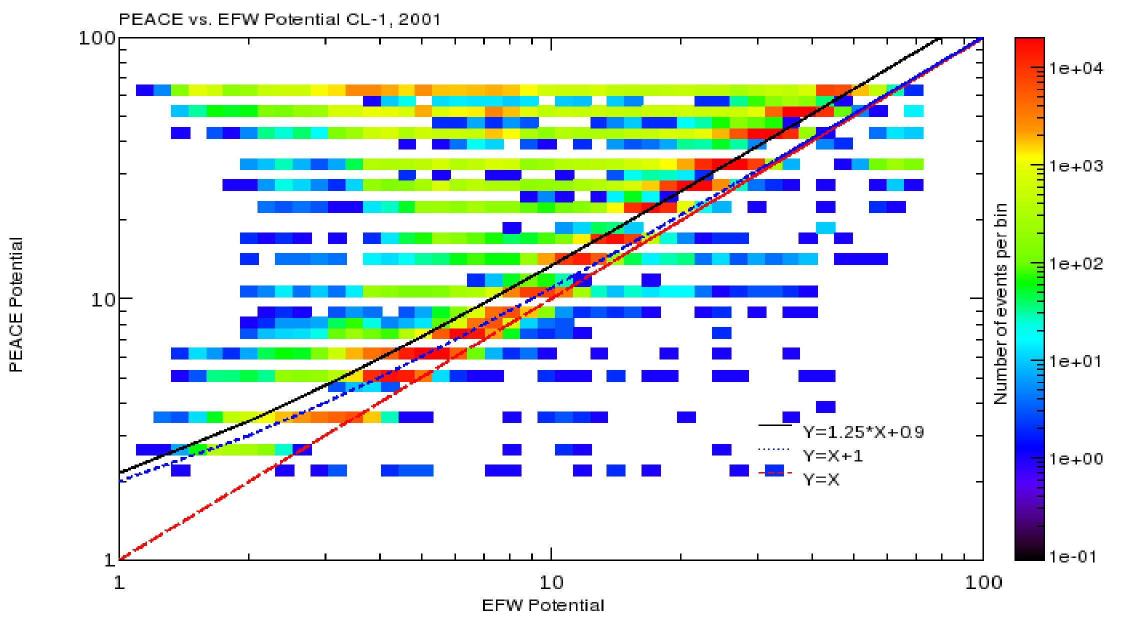

Figure 2 - Cluster satellite potential, as inferred from the PEACE electron measurements, versus the probe-to-spacecraft potential from the EFW probes [Mihaljcic2010]. The black curve is the prediction of the simulations by [Cully2007], which are applicable only in the long Debye length regime, approximately corresponding to potentials above 10 V. SPIS simulations have the potential to apply also to lower potentials (shorter Debye lengths), down to the few volts range.

3.2.2. VC-2 Cluster electron measurements

This case emanates from a repeated community demand for SPIS comparison with observed electron data. Data access will be realized through CAA or by direct request to MSSL (via the contact person).

This case will enable to test an important new functionality of SPIS-SCI: the particle detector (SR-PD) which will allow direct comparison of particle measurements with simulated ones (SR-PD12). The quantification of the photoemission and of the secondary emission will be assessed depending on the input distributions (SR-PS-1, SR-PS-2, SR-PS-8, SR-PS-10). The accuracy of the electron measurement crucially depends on the implementation of the test particle tracking to get sufficient currents for establishing the distribution functions.

We envisage to simulate different plasma conditions relevant to, for instance, solar wind, magnetosheath and inner magnetospheric regions.

3.2.3. VC-4 Solar orbiter E-field and wake

This VC will deal with 1/ the wake effect on the electron instrument (located on an anti-sunward boom) and 2/ the electric potential pattern near the antennas (similar to Figure X). The evolutions of the wake and of the potential pattern for the different plasma conditions presented in the previous VC will be presented, and in addition several solar panel orientations will be simulated.

The effect of non-conducting solar panels on the electric field measurements will be investigated (SR-FGS-1, SR-FGS-2, SR-ESC-3).

3.2.4. VC-5 Solar orbiter electron measurements

Solar orbiter cases are exciting validation cases as they apply to a future mission orbiting in a relatively un-discovered environment. It also applies to Bepi-Colombo which will be in a similar environment. This is a prospective test case as little data exist to compare with [Isensee1981, Katz2001].

We envisage to simulate different plasma conditions relevant to, for instance, the slow wind, fast winds, and typical CME (see Table below). SEP events may be simulated by a modification of the proton distribution function (see below).

	Density (cm^{-3})	Velocity (km/s)	Temperature (eV) electron/proton	Alfvén Mach number	Magnetic field (nT)
Typical wind @0.25AU	120	400	23/31	3.2	67
Slow wind @1AU	12	350	1.3e5/3.e4	17.5	3
Fast wind @1AU	4	750	1e5/2.e5	11	6
Typical CME @1AU	Lower than typical	500 on average	Lower than typical	Lower than typical	Larger than typical

The Debye length for the typical wind (@1AU) conditions is 3.25m.

This case will allow testing how a potential barrier forms around the spacecraft out of combined effects of photoelectron emission and ambient electron density. Such a barrier has been observed in magnetospheric conditions and recently predicted in the close to the Sun environment [Ergun2011] for SP+ context. The evolution of the barrier with heliospheric distance is therefore one of the goal of this VC. It is of particular importance for Solar Orbiter which will hold its electron detector about 4 metres from the spacecraft body.

Similarly to VC-2 the virtual particle detector functionality (SR-PD, SR-ESC-1) will also be explored and one activity of this VC will be to propose predicted distribution functions measured by a simulated electron instrument (SWA/EAS). The quantification of the photoemission and of the secondary emission will be assessed depending on the input distributions (SR-PS-1, SR-PS-2, SR-PS-8, SR-PS-10).

Finally, this case will test the new functionality allowing to define the ambient plasma conditions from the setting of the distribution functions: Maxwellian, Kappa or user defined from observations. Testing the role of the different ambient plasma distributions in the setting of the spacecraft potential is one of the goal of this VC.

3.2.5. VC-12 Cassini electron measurements

Like Cluster, Cassini offers very good validation cases:

- A good set of high-sensitivity plasma instruments onboard, allowing characterization of the environment and comparison to simulation results
- Large and accessible database (PDS plus local access at IRF and IRAP and by contact person at MSSL)
- A wide range of environments, from very low density plasmas in the magnetospheric lobes and the solar wind to very high densities in the ionosphere of Titan.
- Several studies on s/c-plasma interaction and measurement issues previously published [Jacobsen2009, Nilsson2009, Olson2010, Lewis2011]
- High interest from the scientific community
- Relevance for Rosetta, JGO, and ionospheric s/c like Swarm and Demeter
- Crucial dependence on the test particle tracking approach implemented in SPIS-SCI, and use of many other of the new features.

We propose to simulate the following:

- Current-voltage characteristics of the Langmuir probe (RPWS-LP) for varying values of the s/c potential and varying plasma conditions, from quasi-vacuum to dense plasmas in the Titan ionosphere. The simulations can be directly compared to RPWS-LP data available at IRF. Of particular interest is the formation of a barrier for electron attraction by the probe when the spacecraft itself is negative, and how this barrier disappears as the probe goes sufficiently positive and the potential extending from the probe opens a channel to the outside plasma (Figure 3). This situation could first be simulated for a simplified situation of a small sphere (the probe) floating freely outside a large sphere (the spacecraft), as quantitative models for this situation have been set up by [Laframboise1974] and [Olson2010]. A realistic s/c geometry is then simulated in SPIS and compared to the results from the simple two-sphere geometry, the theoretical expectations, previous simulations by [Nilsson2009], and actual data. It is also possible to do comparison simulations using the independent Daedalus code for near-vacuum conditions.
- The influence of photoelectrons and the spacecraft potential on the electron measurements of RPWS-LP and ELS. This includes Langmuir probe bias sweeps and ELS electron spectra with photoelectrons taken into account. Doing this requires the possibility to model a realistic photoelectron distribution (SR-PS-001) and the use of particle back-tracking (SR-PD-010) and is thus a good test case. This case can also be compared to Daedalus near-vacuum simulations.
- The effect of secondary electron emission on the RPWS-LP bias voltage sweeps. Some sweeps [Garnier2011] show a region of negative resistance, a direct effect of secondary emission which could be modelled to validate and demonstrate the SPIS capabilities for treating secondary emission.

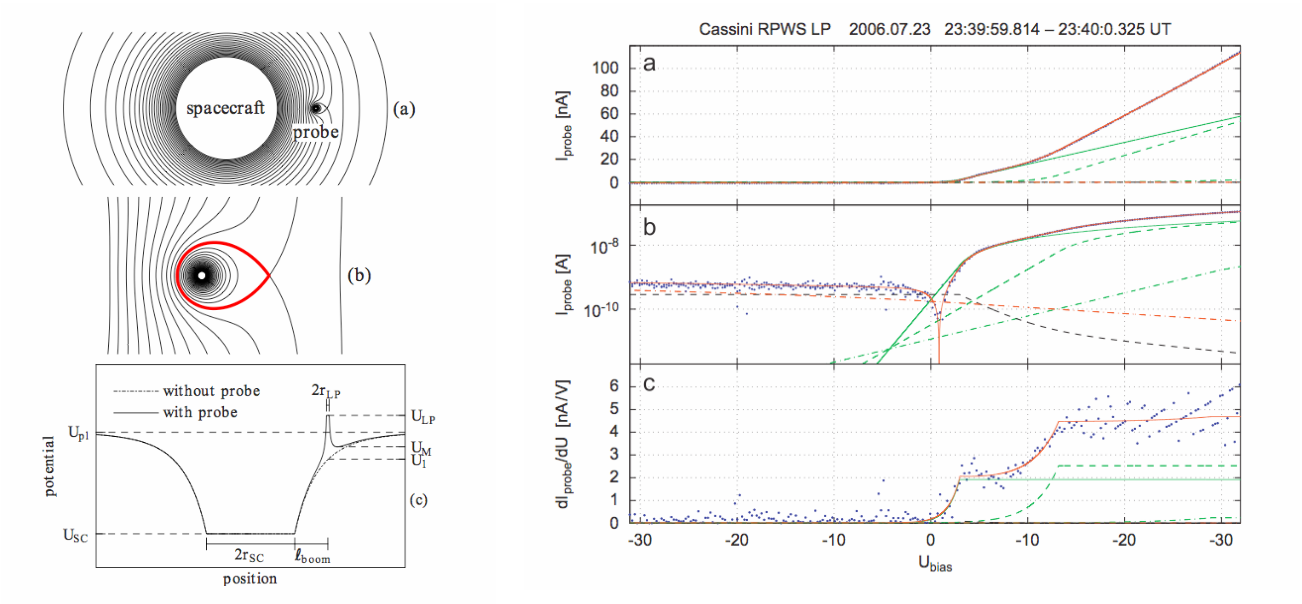

Figure 3 - Left: The barrier forming around an attractive probe on a repelling spacecraft (Figure from [Olson2010]). Right: Such a barrier could possibly explain the apparent two-step nature of the probe current derivative often observed on Cassini RPWS-LP. As the bias voltage increases, the first step would then be due to decreasing repulsion of the few electrons reaching the vicinity of the probe in the presence of the negative spacecraft, while the second step would be due to the opening of the barrier thanks to the influence of the probe potential. (Cassini data from [Wahlund2009])

4. CONCLUSION

We have considered 14 validation cases, suggesting 5 as particularly interesting from the points of view of:

- Current scientific interest
- Relevance for upcoming and ongoing missions
- Relevance for the development effort within SPIS-SCI
- Span of plasma parameters
- Availability of comparison data, other studies, or possibility to compare to alternative codes.

We propose selecting these cases for the SPIS-SCI validation effort.

5. ANNEX: MATRIX OF CORRESPONDENCE BETWEEN THE VC AND THE SR

Annex ESA-SPISSCI_VTP-Annex.v1.0.pdf presents which new SPIS capabilities will be used in each validation case.